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Neutronics analysis of the Colleective Thomson Scattering diagnostic

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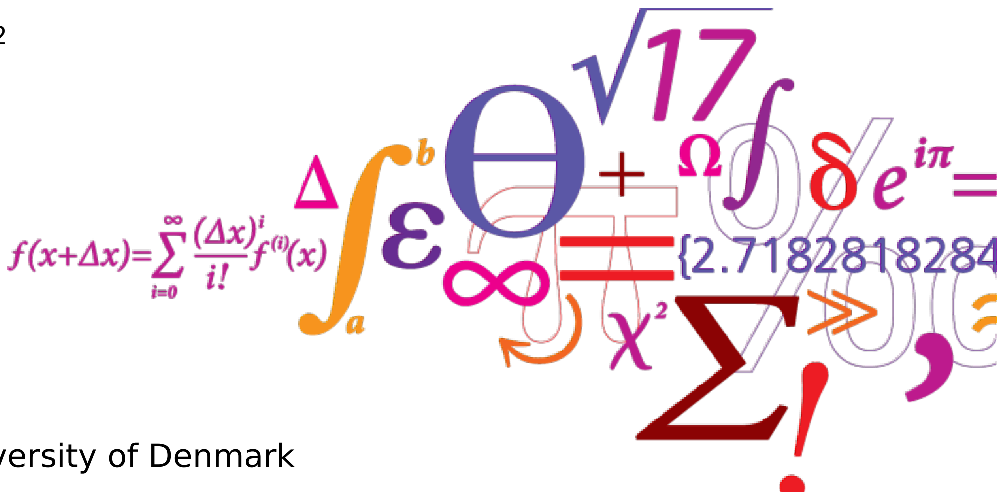

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DTU Nutech

Center for Nuclear Technologies

XIIth ITER Neutronics Meeting, October 10th -12th 2017, Cadarache, France

Purpose and scope

Purpose

Preliminary nuclear analysis performed for the CTS system

Scope

The results obtained in this preliminary analysis will be used for **design support and optimisation** of the CTS system, contributing to the Loads Specification and serving as **input to the thermal analysis** of the CTS in-vessel components.

The models developed will be provided to the PI of EP #12, to be used in a global analysis featuring the contributions of all drawers and systems to the fluxes, heat loads and shutdown dose rates in the port interspace.

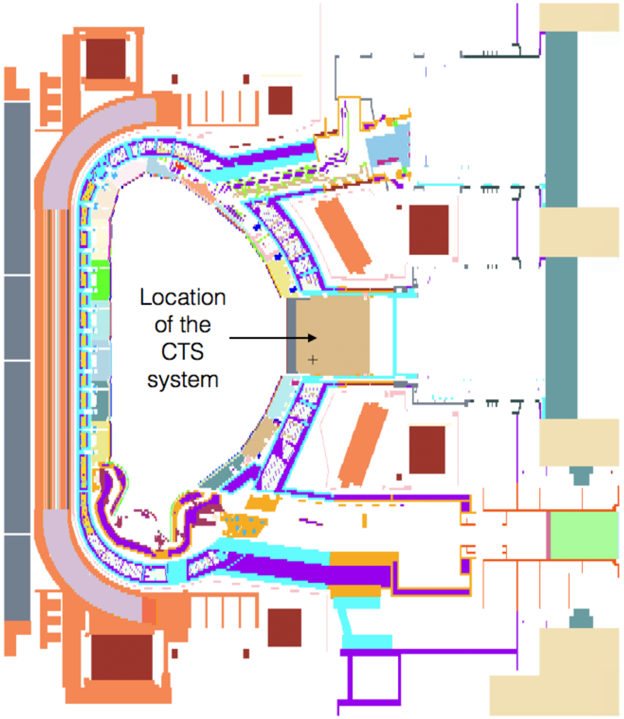
Software and Models

Software

The nuclear analysis was performed using the Monte Carlo code **MCNP6.1**, along with the cross section library **FENDL 2.1** for neutrons and MCPLIB84 for photons.

Models

Reference MCNP model – C-Model 2016 MCNP (TRCFLX v2.1) – provided by IO. Features the most up-to-date design information of the ITER machine, was recently approved and has the necessary space reserved for the CTS system



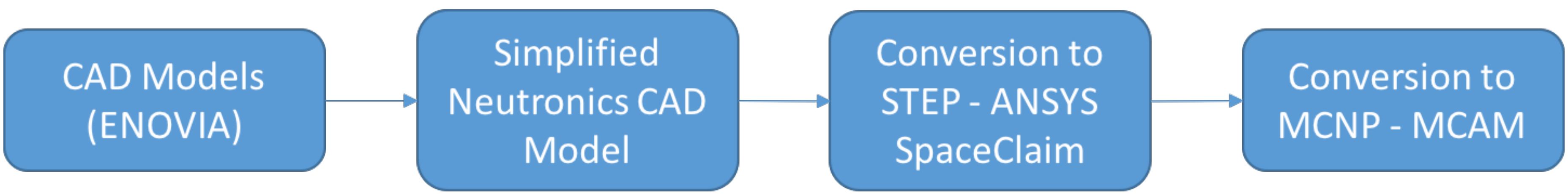
Sectional cut of the reference MCNP model
– C-Model 2016 MCNP (TRCFLX v2.1) at the y=50 cm plane

Model development

Following F4E guidelines we distinguish 3 types of neutronics models:

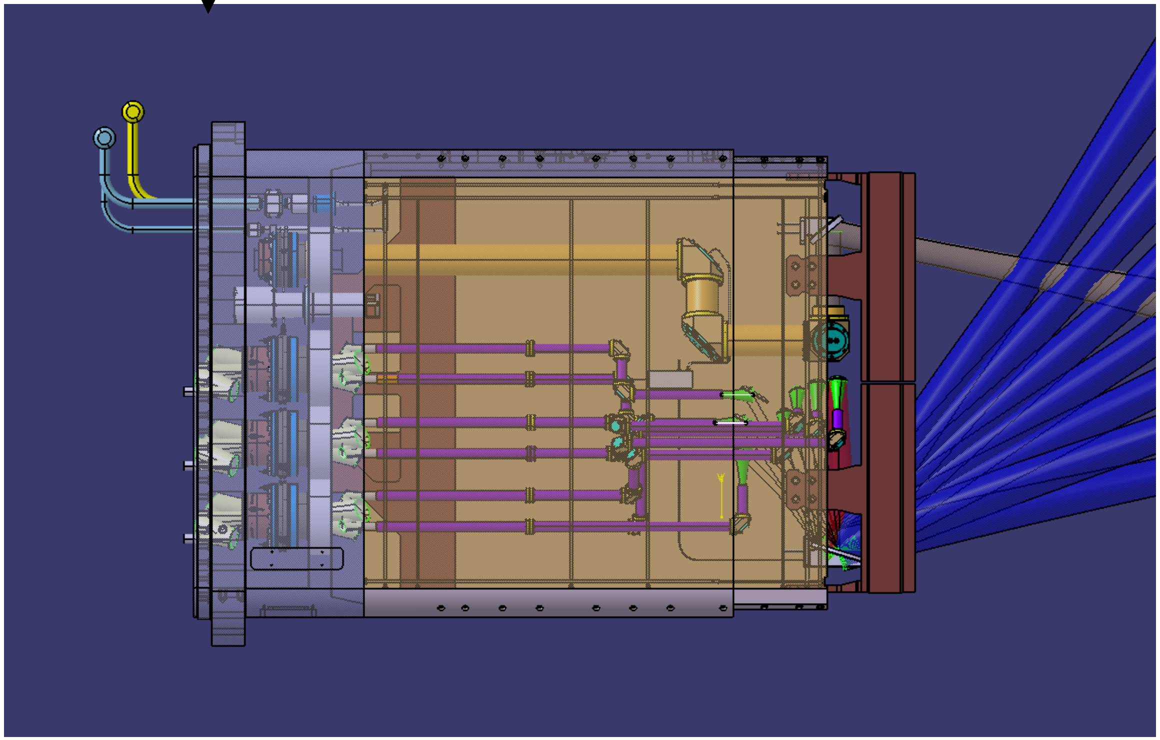
- **Reference model**: standard ITER neutronics MCNP model, provided by IO;
- **System-specific model**: detailed input of the system which is the subject of the nuclear analysis.
- **Integrated model**: System-specific model integrated into reference model.

Modeling workflow



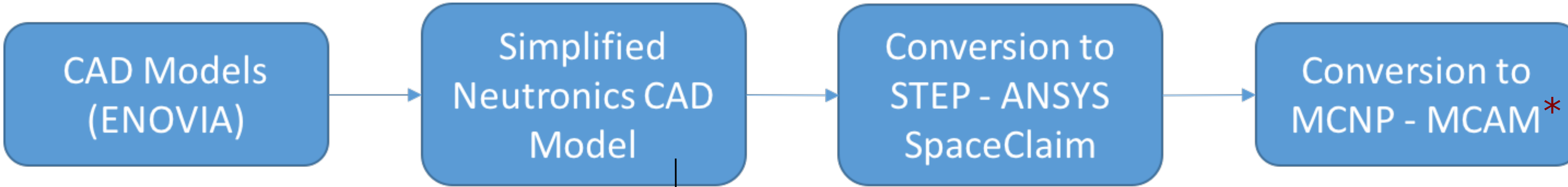
System specific model development

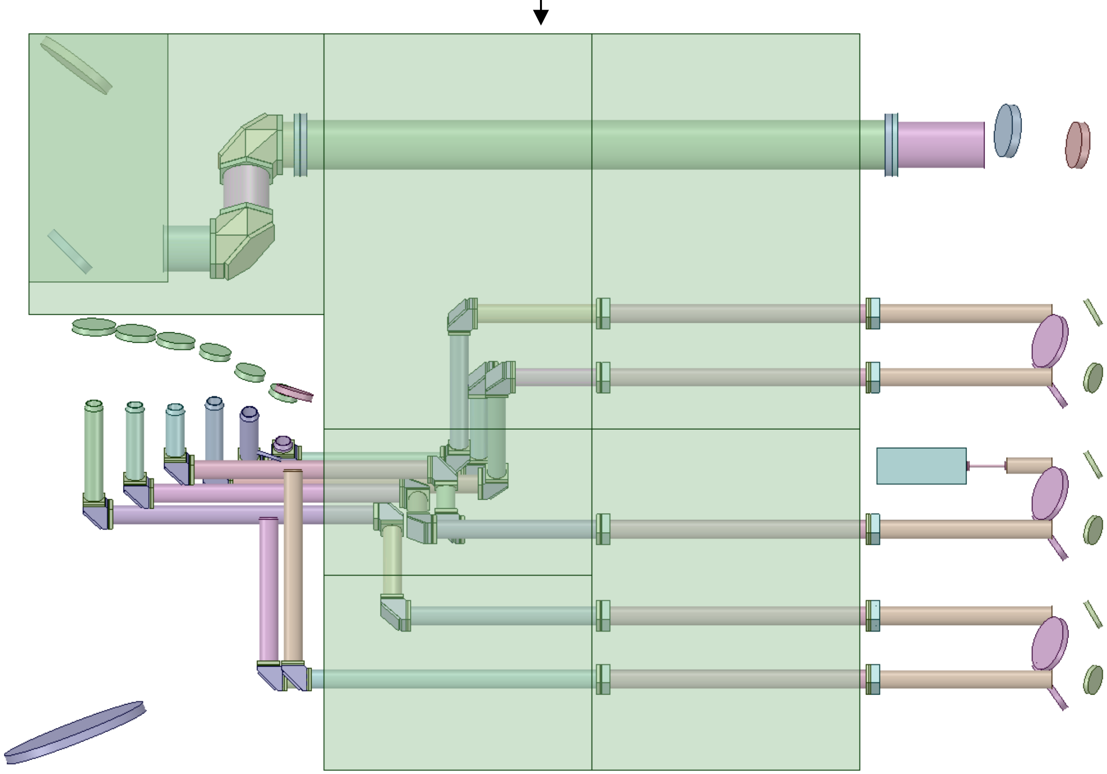
CAD Models (ENOVIA) → Simplified Neutronics CAD Model → Conversion to STEP - ANSYS SpaceClaim → Conversion to MCNP - MCAM



CAD drawing of the CTS system
ENOVIA reference CTS#D85XLF -- L

System-specific model development



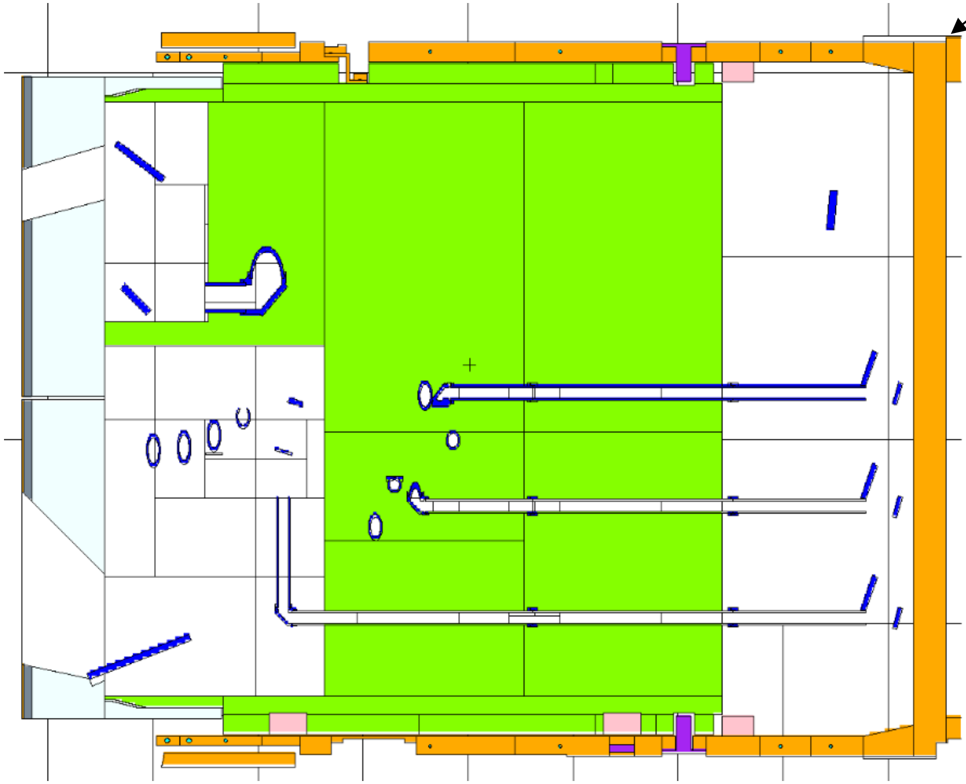


SpaceClaim Model
of the CTS system

*) Y. Wu, FDS Team. CAD-Based Interface Program for Fusion Neutron Transport Simulation. Fusion Eng. Des, 84(2009), 1987-1992.
Y. Wu, J. Song, H. Zheng, et al. CAD-based Monte Carlo program for integrated simulations of nuclear system SuperMC. Ann. Nucl. Energy 82(2015) 161-168.

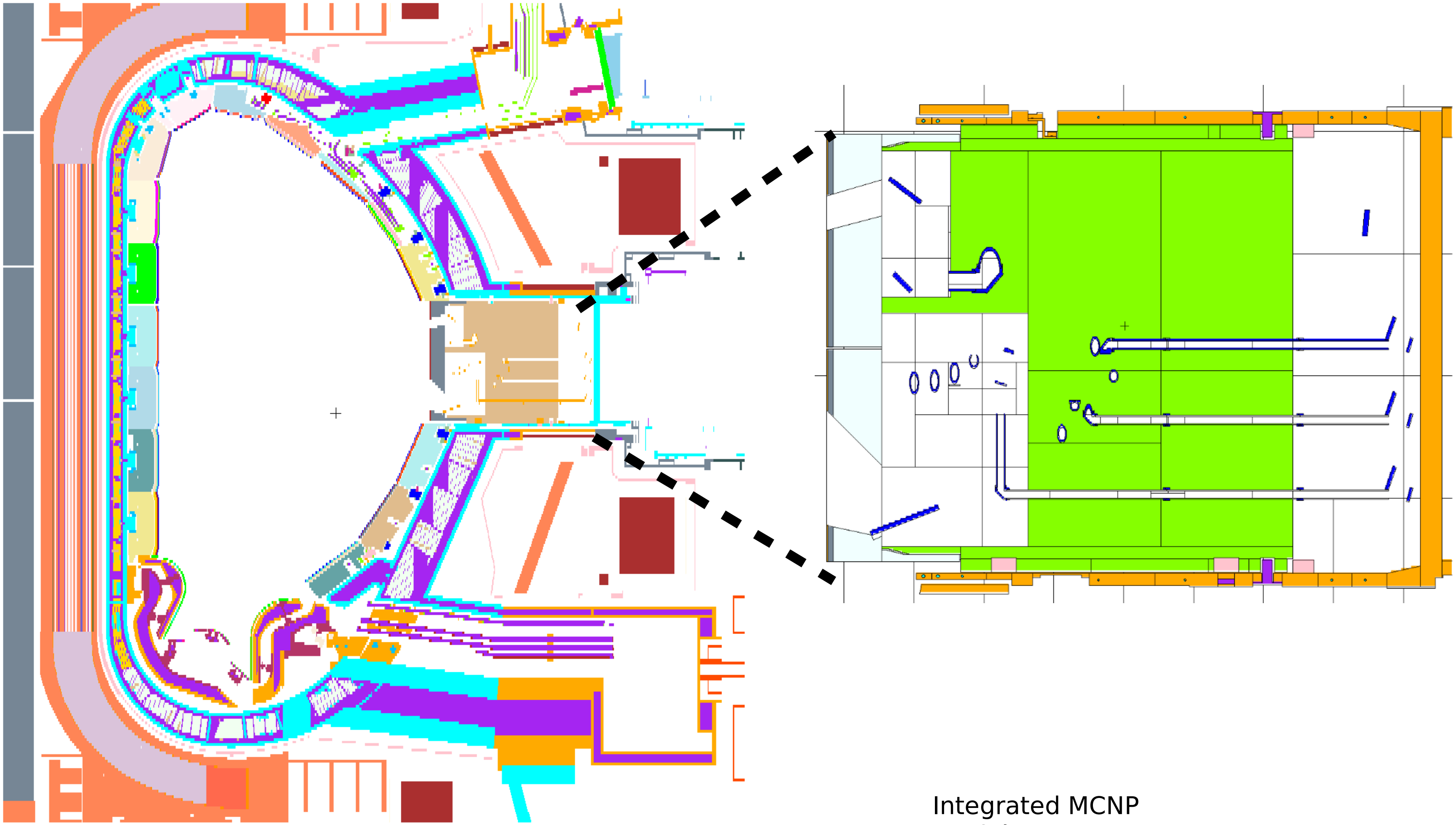
System-specific model development

CAD Models (ENOVIA) → Simplified Neutronics CAD Model → Conversion to STEP - ANSYS SpaceClaim → Conversion to MCNP - MCAM



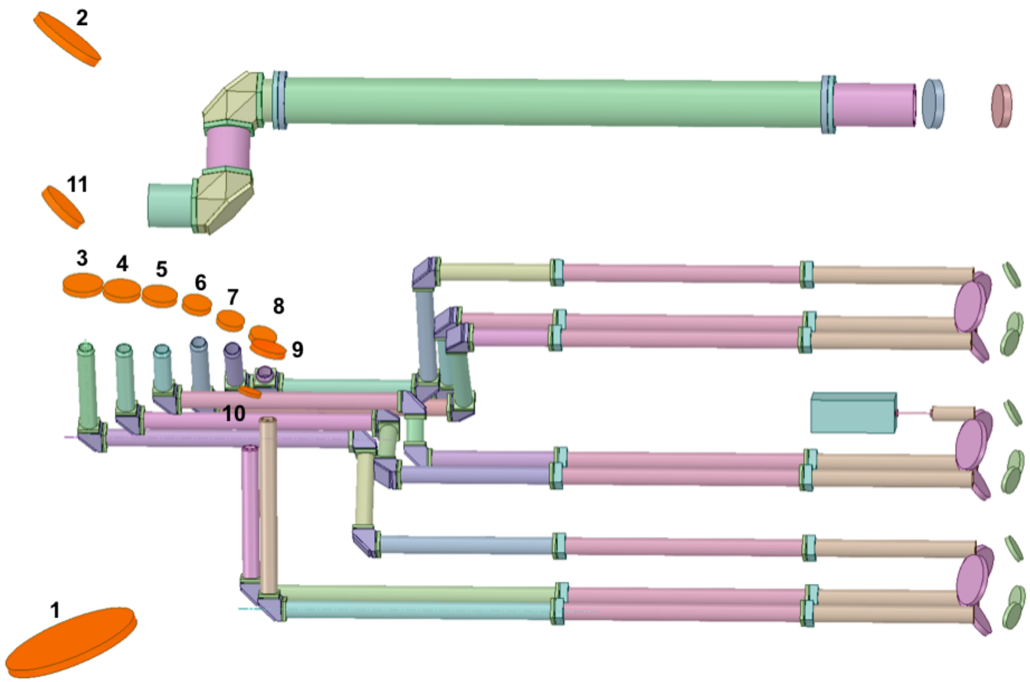
System-specific MCNP model
of the CTS system.
Plane: y=55 cm

Integrated model



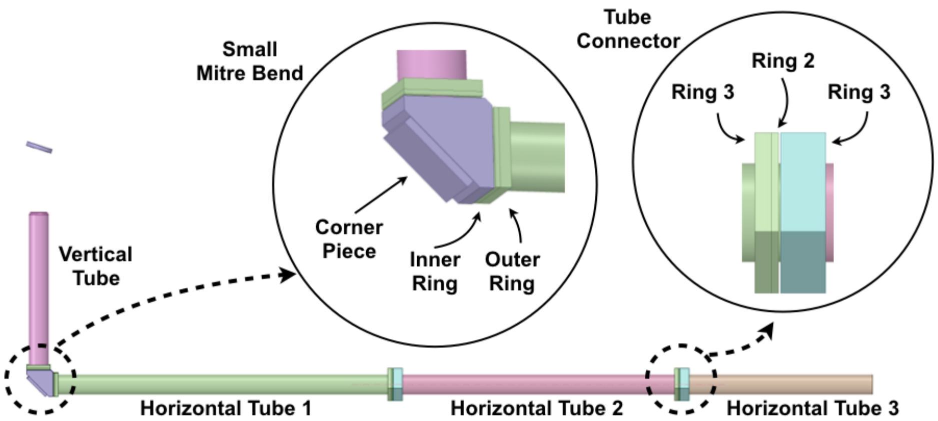
Integrated MCNP
model.
Plane y=55cm

Conserving volumes/masses



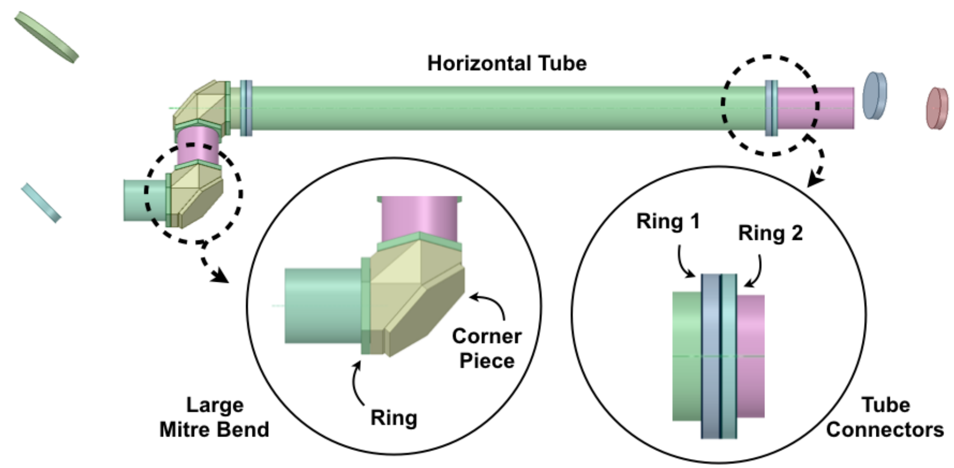
Mirror	Volume from CAD file	Mass from CAD file	Stochastic volume MCNP simulation	Mass stochastic calculation	Simulation statistical error	Relative dev.
	(cm³)	(g)	(cm³)	(g)	(%)	(%)
1	1716.25	13609.84	1716.68	13613.27	0.14	-0.03
2	541.54	4294.41	540.67	4287.50	0.88	0.16
3	103.72	822.50	104.09	825.45	0.42	-0.36
4	92.72	735.25	93.01	737.57	0.44	-0.31
5	82.14	651.34	81.92	649.62	0.46	0.27
6	55.88	443.14	56.18	445.53	0.54	-0.54
7	51.10	405.19	51.77	410.56	0.55	-1.31
8	48.59	385.35	48.99	388.50	0.56	-0.81
9	83.82	664.70	83.62	663.06	0.45	0.25
10	19.52	154.79	19.63	155.69	0.72	-0.58
11	233.60	1852.45	233.51	1851.73	0.33	-0.04

Conserving volumes/masses

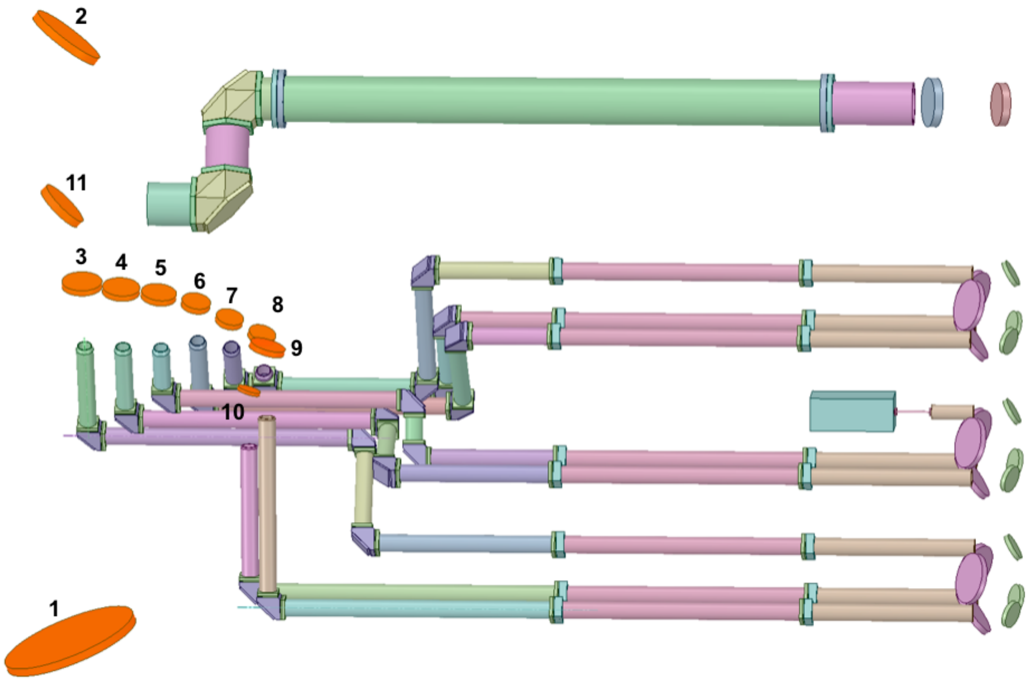


Description	Vol. from CAD	Mass from CAD	Stoc. vol MCNP sim	Mass stoc. calc	Sim. stat err	Rel. dev.
	(cm³)	(g)	(cm³)	(g)	(%)	(%)
Corner Piece	70.04	555.42	69.89	554.23	0.47	-0.21
Outer Ring	7.40	58.67	7.33	58.15	0.87	-0.90
Inner Ring	2.37	18.82	2.36	18.73	1.16	-0.46
Vert. WG	195.91	1553.57	195.25	1548.34	0.25	-0.34
Horiz. WG 1	427.48	3389.91	425.36	3373.13	0.17	-0.49
Horiz. WG 2	356.23	2824.88	355.70	2820.70	0.19	-0.15
Horiz. WG 3	237.49	1883.28	237.37	1882.36	0.22	-0.05
Conn. Ring 1	16.88	133.87	16.86	133.67	0.67	-0.15
Conn. Ring 2	2.37	18.82	2.35	18.59	1.14	-1.19
Conn. Ring 3	7.40	58.67	7.26	57.58	0.87	-1.86

Description	Vol from CAD	Mass from CAD	Stoc vol MCNP sim	Mass stoc calc	Sim stal err	Rel dev.
	(cm³)	(g)	(cm³)	(g)	(%)	(%)
Corner Piece	605.25	4799.63	605.65	4802.84	0.22	0.07
Ring	34.44	273.14	34.50	273.54	0.48	0.15
Horiz. WG	4686.12	37160.95	4685.44	37155.54	0.08	-0.01
Conn. Ring 1	76.46	606.29	76.58	607.27	0.38	0.16
Conn. Ring 2	67.68	536.70	67.76	537.36	0.4	0.12

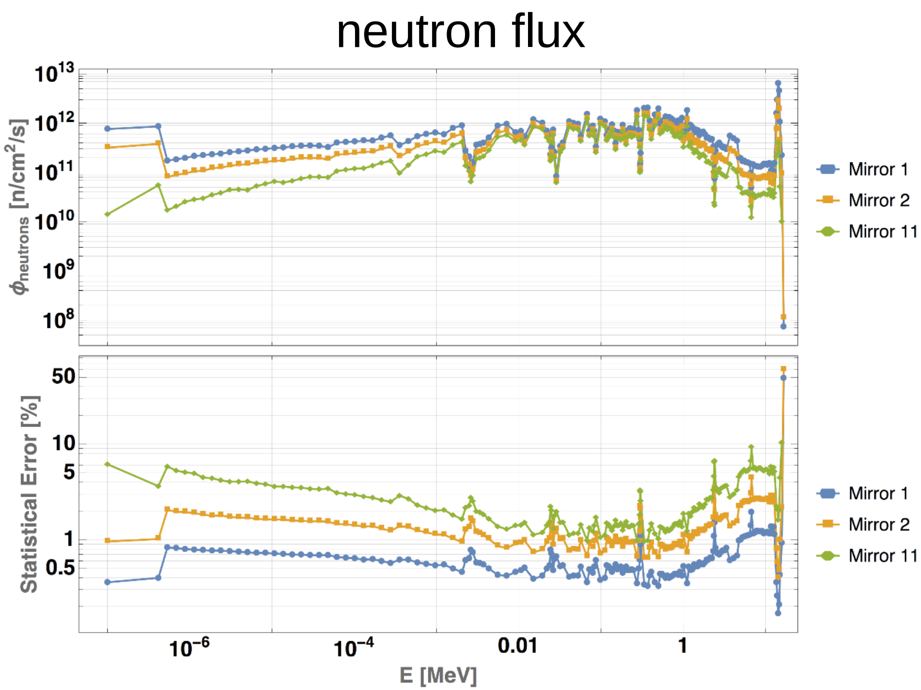


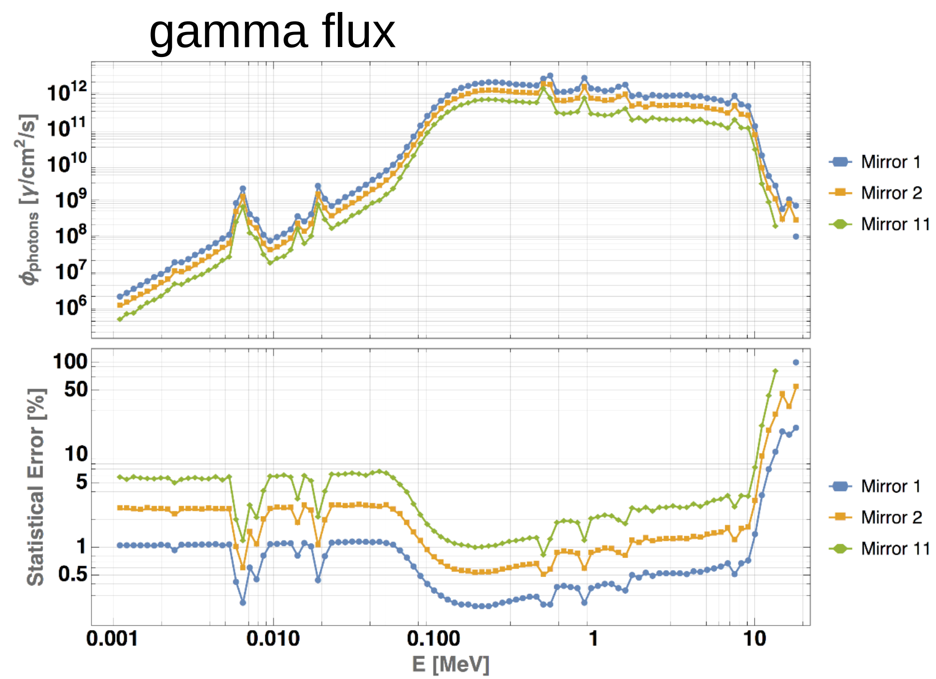
Heat-loads on mirrors



Description	Total Heat Load	Total Heat Load	Stat. Error	Heat Load by Neutrons	Stat. Error	Heat Load by Neutrons	Heat Load by Photons
	(W/cm³)	(W)	(%)	(W/cm³)	(%)	(%)	(%)
1	3.009	5165.46	0.09	0.62059	0.10	20.62	79.38
2	1.536	830.44	0.21	0.28491	0.21	18.55	81.45
3	0.647	67.31	0.60	0.07340	0.82	11.35	88.65
4	0.552	51.34	0.67	0.06322	0.91	11.45	88.55
5	0.497	40.71	0.74	0.05710	0.99	11.49	88.51
6	0.463	26.03	0.91	0.05451	1.22	11.77	88.23
7	0.436	22.56	0.99	0.05389	1.30	12.37	87.63
8	0.406	19.88	0.98	0.05387	1.34	13.27	86.73
9	0.410	34.30	0.79	0.05212	1.08	12.71	87.29
10	0.505	9.91	1.17	0.06300	1.47	12.48	87.52
11	0.651	152.09	0.45	0.07545	0.51	11.58	88.42

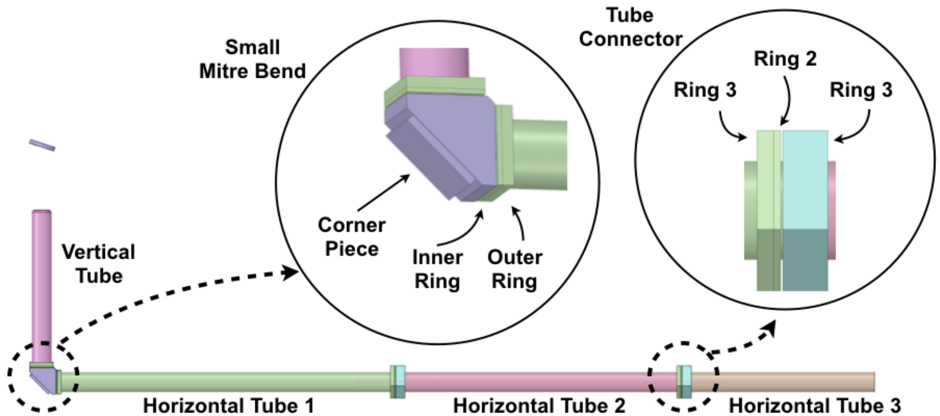
Flux on mirrors





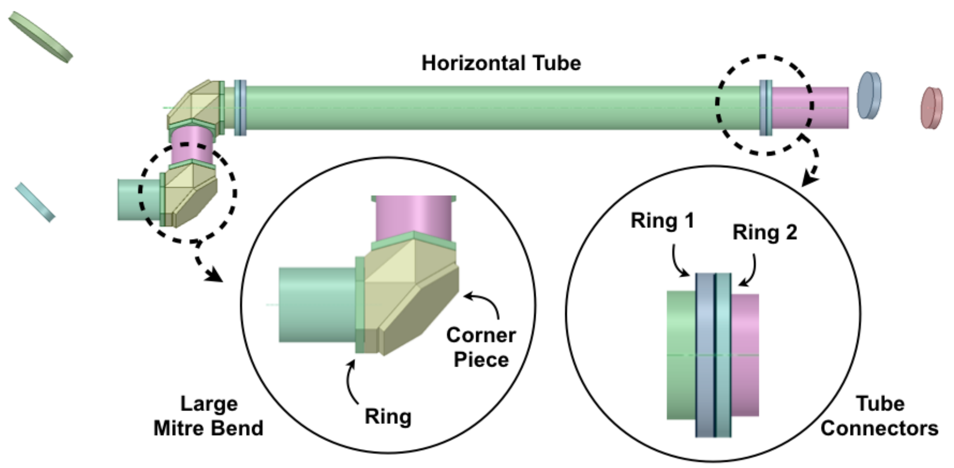
Heat-loads in other components

	Description	Total Heat Load	Total Heat Load	Stat. Error	Heat Load by Neutrons	Stat. Error	Heat Load by Neutrons	Heat Load by Photons
		(W/cm3)	(W)	(%)	(W/cm3)	(%)	(%)	(%)
Small Mitre Bend	Corner Piece	0.878	61.34	0.61	0.16752	0.75	19.09	80.91
	Outer Ring	0.893	6.55	1.21	0.16915	1.71	18.95	81.05
	Inner Ring	0.911	2.15	1.73	0.16857	2.49	18.50	81.50
Collector Line	Vert. WG	0.807	157.55	0.32	0.13591	0.37	16.84	83.16
	Horiz. WG 1	0.226	96.16	0.49	0.03574	0.80	15.81	84.19
	Horiz. WG 2	0.001	0.43	7.60	0.00025	13.95	20.30	79.70
	Horiz. WG 3	0.000	0.03	26.42	0.00003	40.96	28.59	71.41
	Conn. Ring 1	0.005	0.09	11.62	0.00055	14.53	11.82	88.18
	Conn. Ring 2	0.004	0.01	15.22	0.00056	18.71	14.10	85.90
	Conn. Ring 3	0.005	0.03	14.16	0.00069	14.85	15.03	84.97

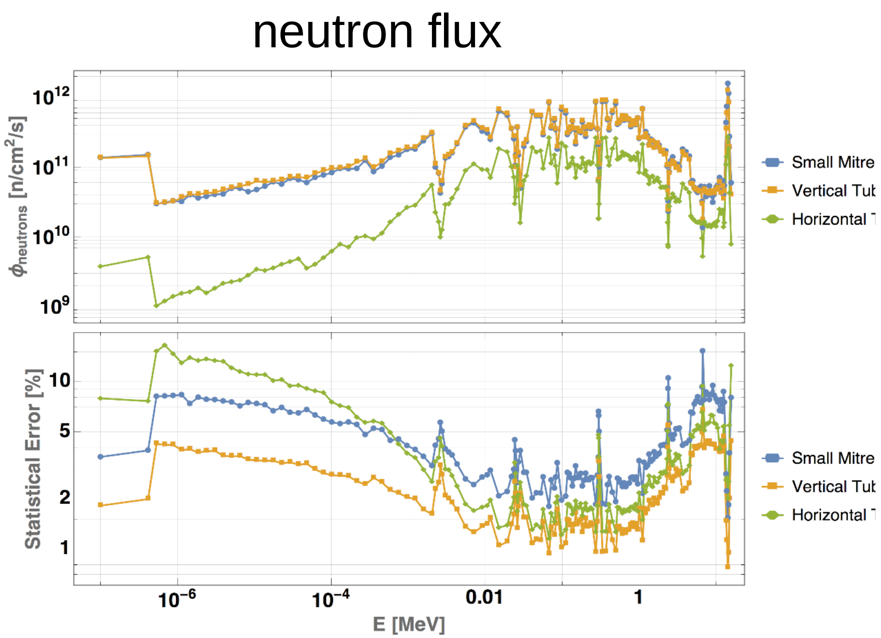


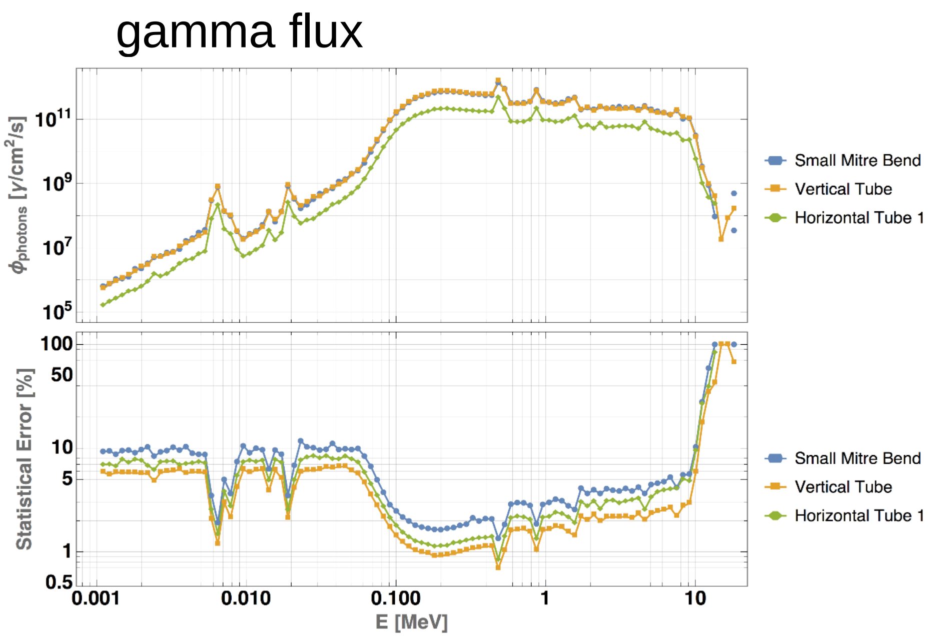
Heat-loads in other components

	Description	Total Heat Load	Total Heat Load	Stat. Error	Heat Load by Neutrons	Stat. Error	Heat Load by Neutrons	Heat Load by Photons
		(W/cm^3)	(W)	(%)	(W/cm^3)	(%)	(%)	(%)
Large Mitre Bend	Corner Piece	0.102	61.54	0.78	0.01290	0.95	12.70	87.30
	Ring	0.061	2.09	2.20	0.00777	2.47	12.83	87.17
Probe	Horiz. WG	0.005	22.90	1.33	0.00060	1.69	12.31	87.69
	Conn. Ring 1	0.041	3.16	2.17	0.00483	2.44	11.70	88.30
	Conn. Ring 2	0.048	3.27	2.09	0.00563	2.28	11.68	88.32



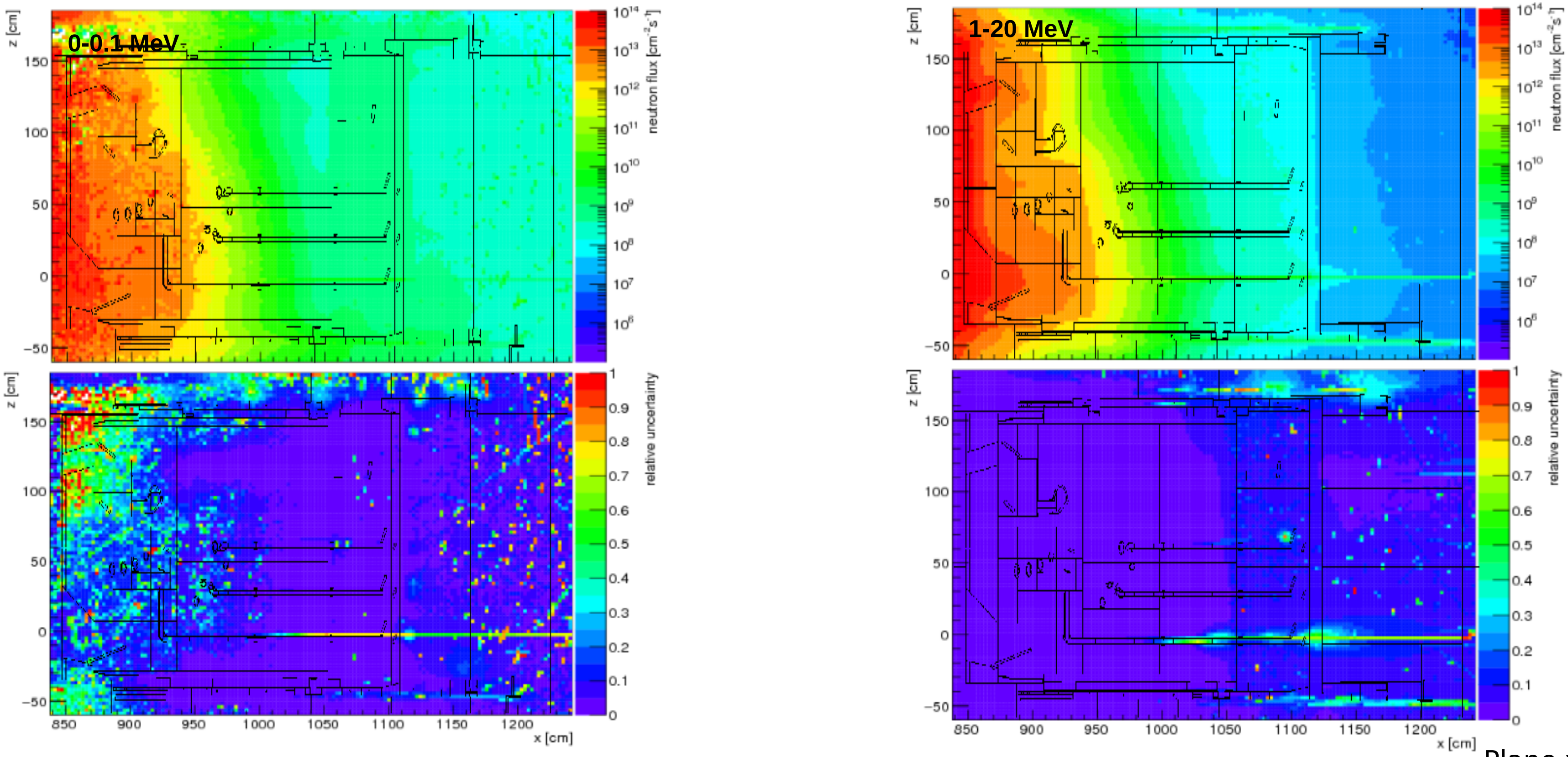
Flux on structures





Flux maps

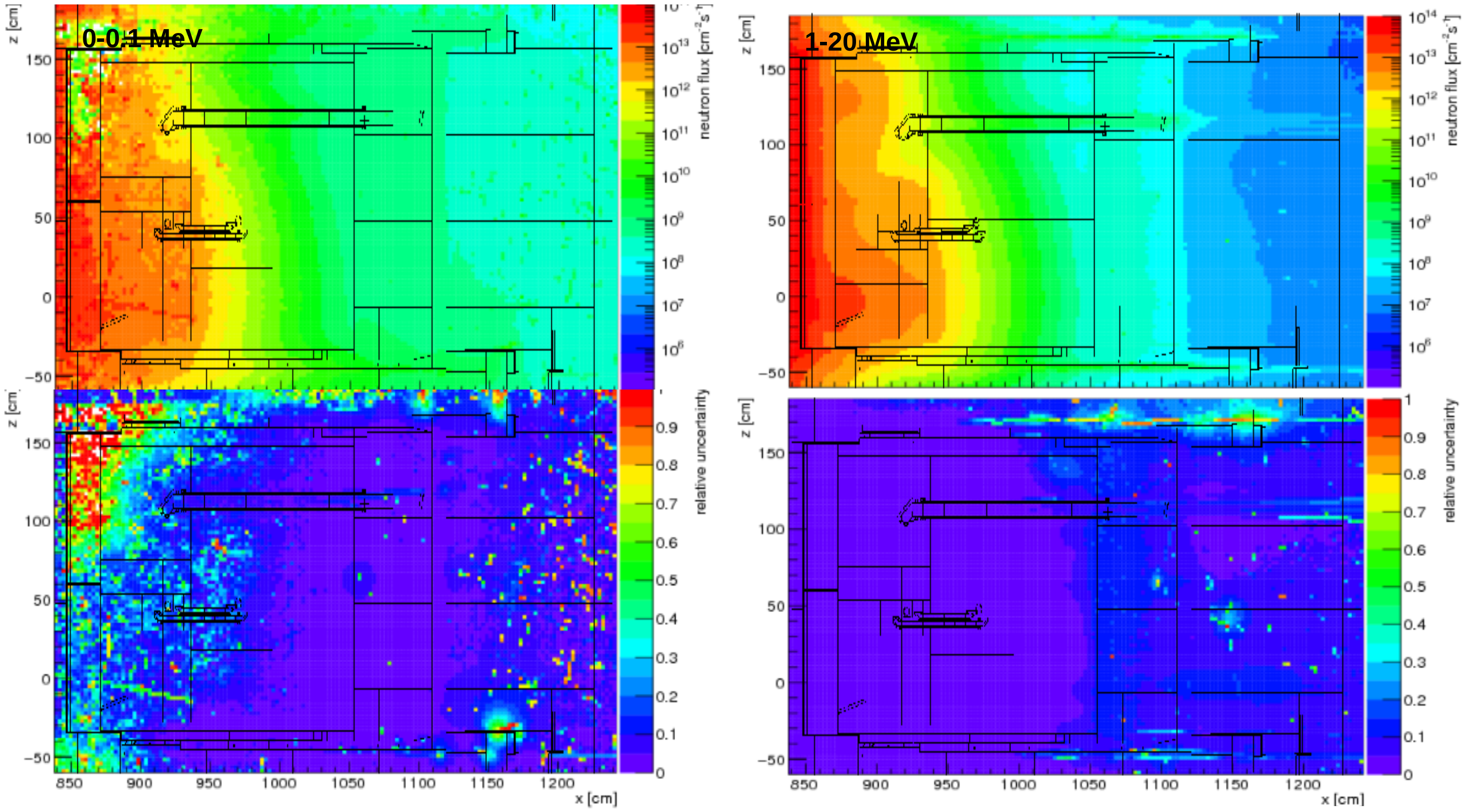
To identify weakness in the design in terms of neutrons streaming, neutron flux mesh plots are considered – based on ADVANTG weight windows



Plane y=55cm

Clearly the receiver line behind the (larger) receiver DFW cut-out is hosting streaming neutrons. In addition streaming paths along the upper and lower frames of the port cell can be identified.

Flux maps

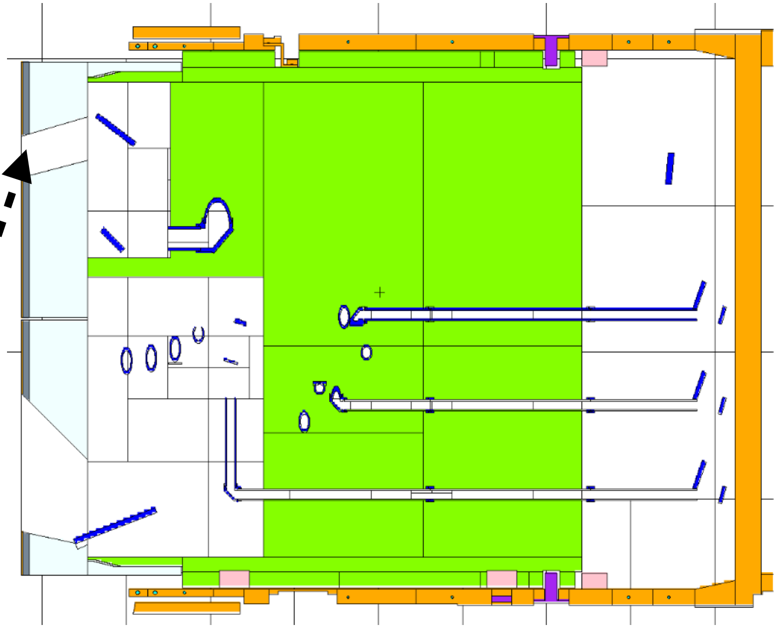


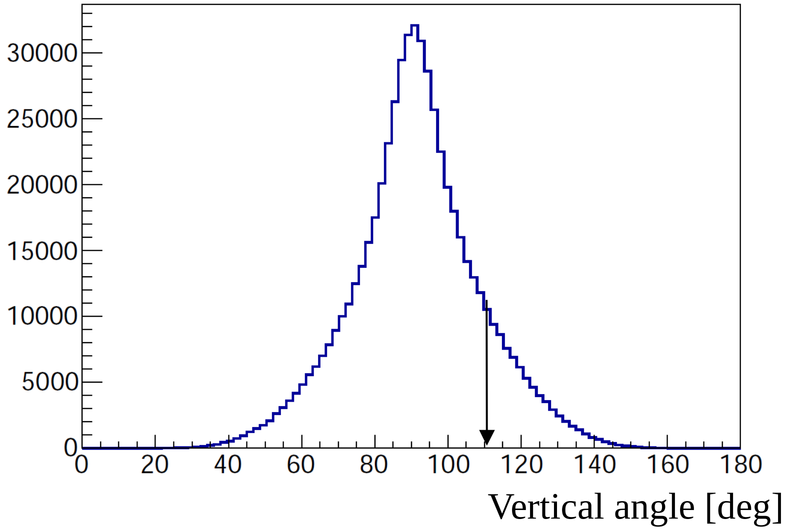
Plane y=65.5cm

Despite it’s larger diameter, streaming in the launcher waveguide is less pronounced than what is observed in some receiver waveguides

Design support: tilting launcher waveguide to reduce fast neutron streaming

- Introducing dog-legs in the launcher waveguide significantly degrade the performance of the CTS system
- One option is to tilt the launcher vertically, thus pointing away from the plasma center
- To get feeling for the maximum gain achievable by tilting the launcher waveguide:
  - SSW card introduced on the cut-out surface
  - Neutrons > 10MeV are tallied
- Vertical angle shown below



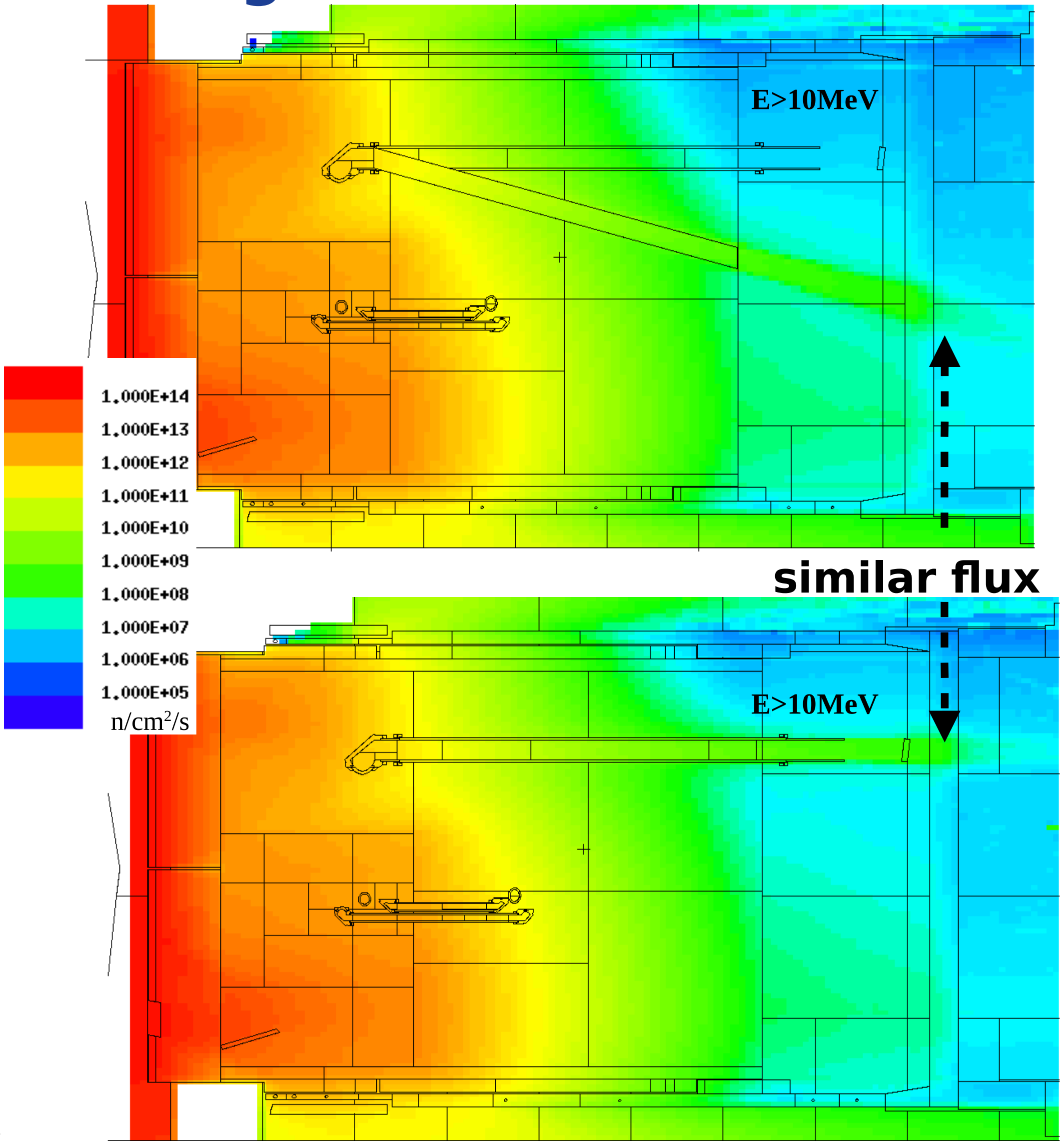


- From this over-optimistic approach, based on a void geometry, more than 50% reduction seems feasible from 20 degree tilt
- => launch in-depth study, based on the System-specific model

Design support: tilting launcher waveguide to reduce fast neutron streaming

- Based on the **System-specific model**, using IMP:n=0 in all cells adjacent to the CTS
- Tilt the void inside of the launcher waveguide by 0 and 20 degree
- Mesh at y=65.5cm, E_n>10MeV

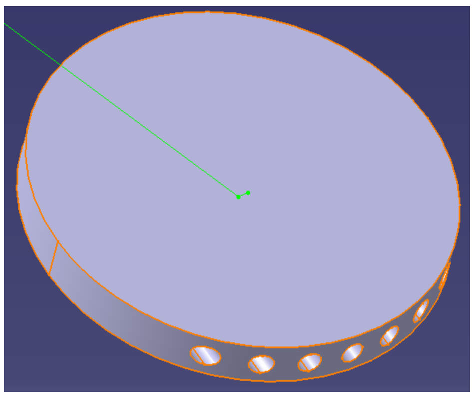
- Unfortunately, tilting the launcher, gives <u>no benefits</u> in terms fast neutron streaming

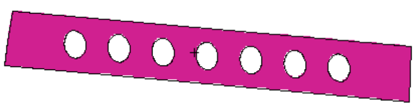


Plane y=65.5cm

Design support: heat-loads in different materials

Water filled Cooling channels added to launcher mirror, and heat-load studied as a function of material





Heat-loads in SS-316L and CuCrZr are similar, and mostly unaffected by the presence of water.
Heat-load in tungsten is about twice

Description	Component	Total Heat Load (W/cm³)	Total Heat Load (W)	Stat. Error (%)	Heat Load Neutrons (W/cm³)	Stat. Error (%)	Heat Load by Neutrons (%)	Heat Load Photons (%)
Stainless Steel	Mirror	1,53	830,44	0,21	0,28	0,21	18,55	81,45
Stainless Steel w/ Cooling	Mirror	1,58	711,76	0,94	0,28	0,94	17,84	82,16
	Tube 1	1,45	21,09	2,08	1,30	2,26	89,76	10,24
	Tube 2	1,49	21,17	2,12	1,33	2,30	89,75	10,25
	Tube 3	1,48	21,07	2,11	1,33	2,29	89,96	10,04
	Tube 4	1,52	20,02	2,20	1,38	2,37	90,49	9,51
	1,42	18,66	2,17	1,27	2,35	89,61	10,39	
	1,43	15,88	2,42	1,29	2,62	90,32	9,68	
	1,45	16,14	2,37	1,31	2,57	90,03	9,97	
Tungsten	Mirror	3,26	1765,10	0,90	0,05	0,81	1,67	98,33
Tungsten w/ Cooling	Mirror	3,63	1633,37	0,90	0,05	0,82	1,48	98,52
	1,44	21,02	2,17	1,32	2,32	91,56	8,44	
	1,48	21,10	2,15	1,36	2,30	91,46	8,54	
	1,46	20,73	2,16	1,34	2,30	91,92	8,08	
	1,47	19,29	2,28	1,35	2,42	91,94	8,06	
	1,41	18,49	2,23	1,29	2,38	91,81	8,19	
	1,39	15,48	2,59	1,28	2,76	92,11	7,89	
	1,39	15,44	2,45	1,27	2,61	91,75	8,25	
CuCrZr	Mirror	1,63	882,10	0,91	0,26	0,92	15,85	84,15
CuCrZrl w/ Cooling	Mirror	1,67	751,01	0,93	0,26	0,94	15,44	84,56
	1,45	21,20	2,10	1,31	2,27	90,37	9,63	
	1,50	21,35	2,11	1,35	2,28	90,09	9,91	
	1,50	21,28	2,12	1,36	2,29	90,69	9,31	
	1,52	20,04	2,22	1,38	2,38	90,88	9,12	
	1,40	18,38	2,18	1,25	2,38	89,78	10,22	
	1,42	15,82	2,43	1,29	2,62	90,45	9,55	
	1,46	16,23	2,38	1,32	2,57	90,33	9,67	

Conclusions

The magnitudes of the nuclear heat loads and neutron fluxes obtained in the simulations seem consistent with results from previous analyses (IO_UID_S35Y7M).

Peak values of the order of **3 W/cm^3** were obtained in the plasma-facing **receiver** mirror, where a total power of **5.2 kW** is deposited;
In the **launcher** mirror, the heat load is **1.5 W/cm^3**.
The heat loads in the remaining components are < **1 W/cm3**

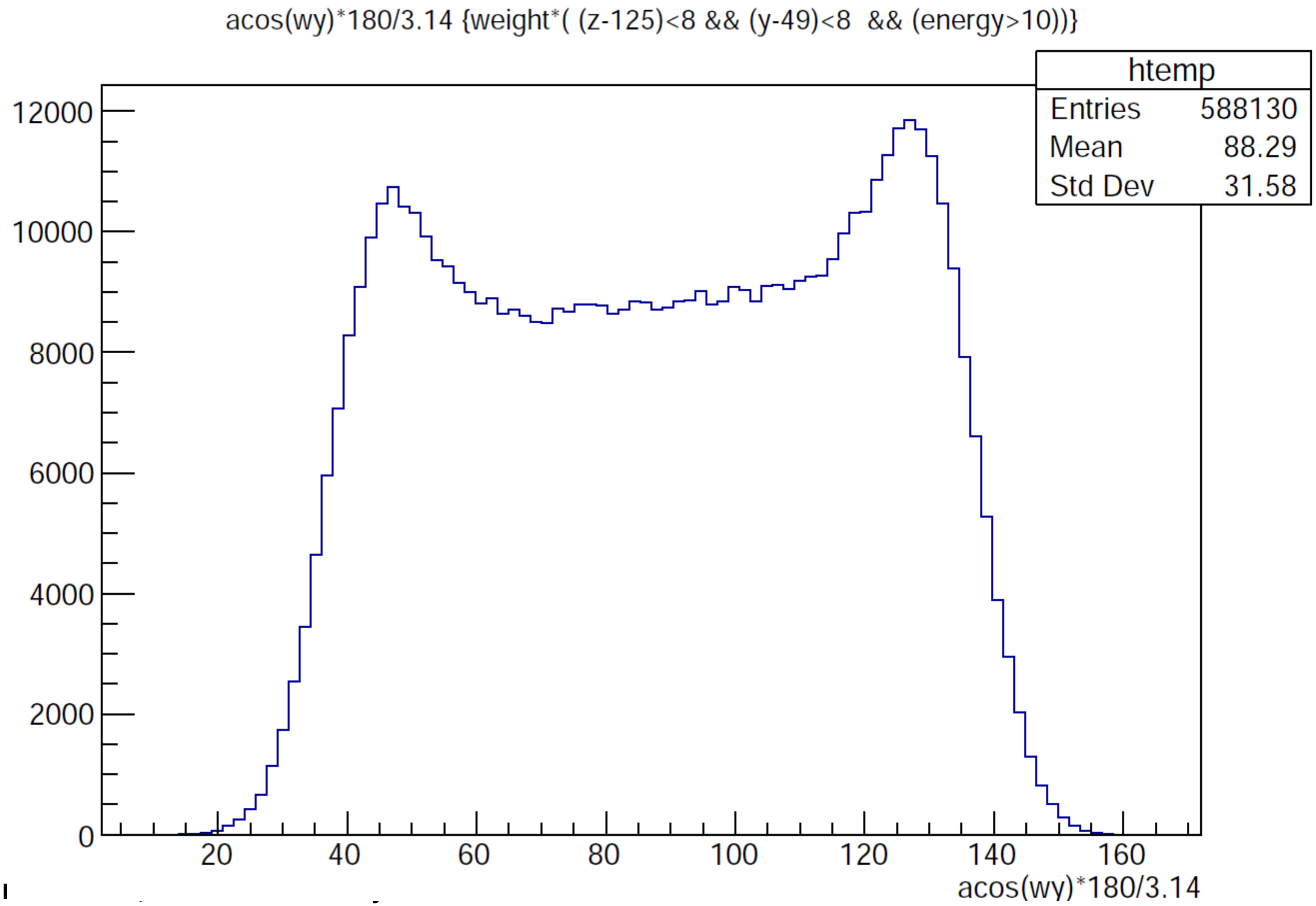
For components located at the back of the system, heat loads are < **10 mW/cm^3**

The neutron fluxes at the closure plate are ~**10^8 cm^{-2}s^{-1}** for E:0-1 MeV, and about 1 tenth of that for E: 1-20 MeV.

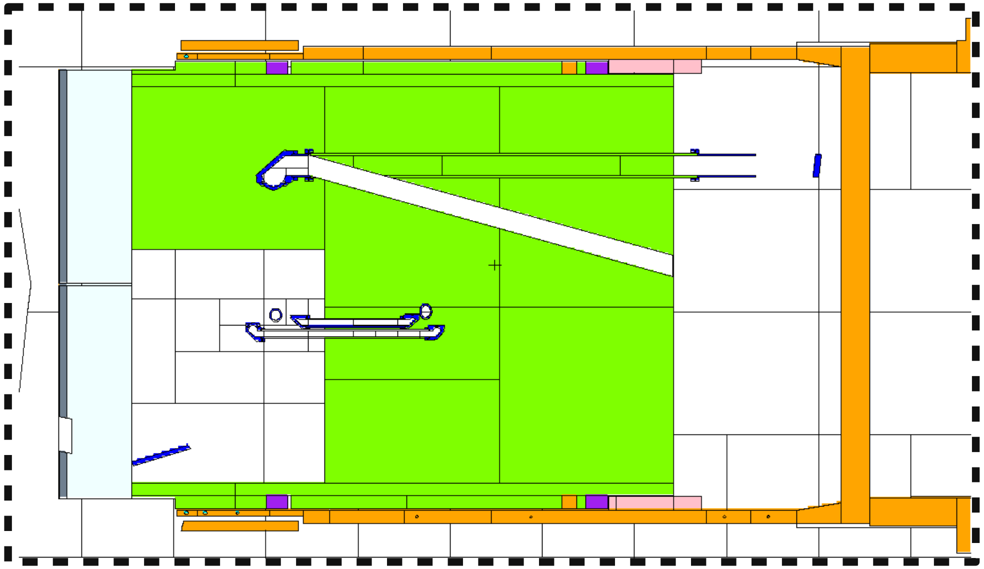
It is estimated that with such neutron fluxes the shutdown dose rates may exceed 100 μSi/h at the closure plate - taking only into account a detailed modeling of the CTS in Equatorial Port Plug #12 (drawer 3), while neighboring drawers are modeled as homogenized bulk materials (not-conservative).

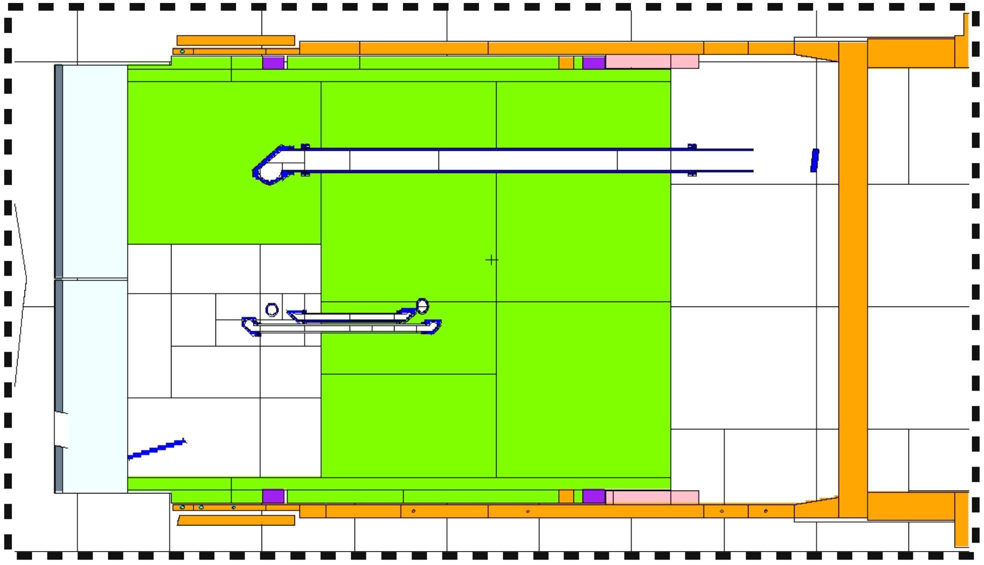
Backup slides

Tilting the launcher waveguide: horizontal distribution



Tilting the launcher waveguide: geometry





Weight windows – from ADVANTG